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CHARACTERISTICS OF THE EXTRATERRESTRIAL CURRENT SYSTEM: EXPLORER VI AND PIONEER V* †

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The purpose of this note is to present some of the characteristics of the current system discovered by Explorer VI. These currents are located at altitudes beyond 6 earth radii and thus lie outside the Van Allen radiation zones. The presence of the current system gives rise to a major large-scale perturbation of the distant geomagnetic field. It was on the basis of this field perturbation, which was observed by the Explorer VI magnetometer, that the existence of this current was established. In earlier work which has been published [Sonett, 1960a,b], it has been shown that the currents have the following characteristics. They (1) are a persistent feature of the distant field and occur on both magnetically quiet as well as magnetically disturbed days, (2) tend to be localized spatially, perhaps in the form of a toroidal ring, (3) show a time variation, (4) probably do not represent termination of the geomagnetic field (which appears to take place beyond 10 R_e), and (5) have a total magnitude which is probably of the order of 10^6 amperes.

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These conclusions were based on a preliminary examination of the geomagnetic field deviations associated with the current. In order to establish the characteristics of the current system itself, a model has been hypothesized and the resultant field consisting of the geomagnetic and perturbation field has been computed. These calculations have been compared with the observed field in order to (1) test the applicability of the model and (2) evaluate the parameters of the current system which best fit the data. The purpose of the present discussion is to present some preliminary, but interesting, results of these model calculations.

The search coil magnetometer measures the component of B perpendicular to the spin axis of the payload, designated $|B_\perp|$. [Sonett, 1960c] In addition there is a related experiment in the payload which provides information on the direction of the field component perpendicular to the spin axis. This consists of an aspect indicator which measures the angle, Φ, between $\vec{B}_\perp$ and the vector from the vehicle to the sun projected into the vehicle's equator.

Figure 1 represents the characteristic results from these two experiments obtained along the outward branch of an orbital pass. $|B_\perp|$ and Φ are shown as a function of geocentric altitude. In addition to the data points, heavy curves are shown representing theoretical values of the extrapolated geomagnetic field. The data represents an actual comparison between the absolute experimental values and the theoretical calculations (based on a spherical harmonic expansion of the earth's field as measured at the surface). This figure shows clear evidence in both measurements of the perturbation of the distant field. Figure 2 presents an expanded view of the region of

interest (actually the data was taken 25-1/2 hours earlier than that shown in Figure 1).

Explorer VI provided two kinds of telemetered data. The magnetometer signal (a sinusoid at the spin frequency of the payload whose amplitude is proportional to $|B_\perp|$) modulated a subcarrier oscillator whose output was telemetered to the ground as a direct analog signal. The magnetometer signal also went to a digital-telemetry-unit ("telebit"), where the analog signal was converted into a digital signal. A binary "word" (or number) was continuously stored in a memory unit. The memory unit was sampled periodically and the digital word was telemetered to the ground stations. The use of these two calibrated outputs provided a check on the quality and accuracy of the telemetered data.

Digital data obtained simultaneously with the analog data has been included in Figure 2 so the two output signals may be compared. The length of the vertical line associated with the digital data represents the maximum uncertainty in the measurement as a consequence of digitization. There is substantial agreement between the two results.

Figure 3 is a diagram presenting the essential features of the model calculation. The assumptions involved are the following:

(1) The current volume is cylindrical in shape with a circular cross-section of radius, a.

(2) The center of the current-cylinder is located at a distance R_o from the center of the earth and lies in the geomagnetic equator.

(3) The total current has a magnitude I which is uniformly distributed

throughout the volume and flows westward.

One analog of such a model would be a circular current enclosing the earth as envisaged long ago by Stormer [1911] and by Chapman and Ferraro [1941]. This approach to the problem is essentially phenomenological; there is no consideration of the microscopic motion of particles. The utility of such a simple model lies in simplifying the calculations of the perturbation field due to the current. On the basis of individual particle motion in the inhomogeneous magnetic field, it has previously been suggested that such a model is physically meaningful [Singer, 1957], though we considered it significant that ΔB shows gross changes, thus raising a question as to the applicability of Alfven perturbation theory.

The calculations are complicated by the necessity of specifying the trajectory of the payload and the fact that the magnetometer detects a rather arbitrary component of the magnetic field which depends on the orientation of the spin axis in space. The calculations were programmed for a computer as follows:

At a given point along the trajectory,

(1) the perturbation field due to the current was computed;

(2) it was added vectorially to the geomagnetic field obtained from the same spherical harmonic expansion as was used previously;

(3) both the net $|B_\perp|$ and Φ were computed.

The results of these calculations are presented in Figure 4. A close fit to the experimental data is obtained for the following values of the parameters

$$R_o = 60.10^3 \text{ km} (\simeq 10\ R_e)$$

$$I = 5.10^6 \text{ amperes}$$

$a = 3\ R_e$ or less (no penetration of the current by Explorer VI on this day)

The region of space being sampled by the Explorer VI payload lies on the evening side of the earth at about 2100 hours local time. Clearly, it is desirable to sample a different region of space to determine the gross characteristics of the current system. This is particularly important insofar as it relates to closure of the current system and to the establishment of whether or not the perturbations are due to a toroidal ring current. Such an opportunity was provided by Pioneer V which carried a similar magnetometer and which passed through the geomagnetic field on the afternoon side of the earth.

Figure 5 presents the sampled, digital field measurements obtained during the early part of the Pioneer V flight through the geomagnetic field. Also shown are the results of the model calculation using the following parameters:

$$R_o = 50{,}000 \text{ km}$$
$$I = 5.10^6 \text{ amp}$$
$$a = 3\ R_e$$

An important feature of the agreement is the fact that the data cannot be adequately fit for values of a less than 3. Therefore, this establishes the minimum cross-section of the ring at this time, just as the data in Figure 5 sets an upper bound of 3 earth radii at the time

those measurements were made.

It is considered that the close agreement with the model and the similarity of the values of the parameters in these two regions of space strongly suggests the existence of a ring current around the earth at altitudes of approximately 10 earth radii.

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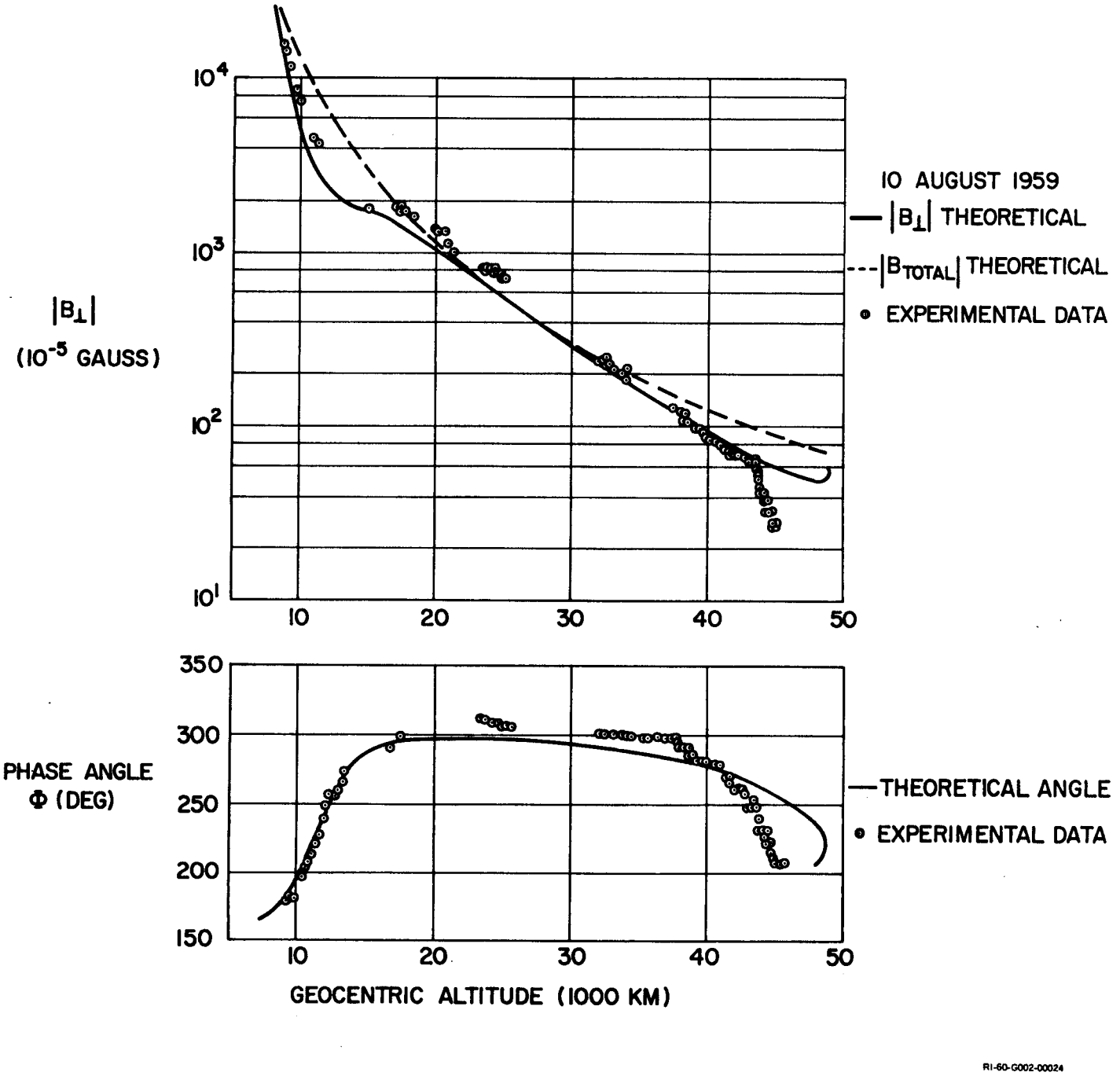

Figure 1. The Extraterrestrial Field As A Function Of Geocentric Altitude

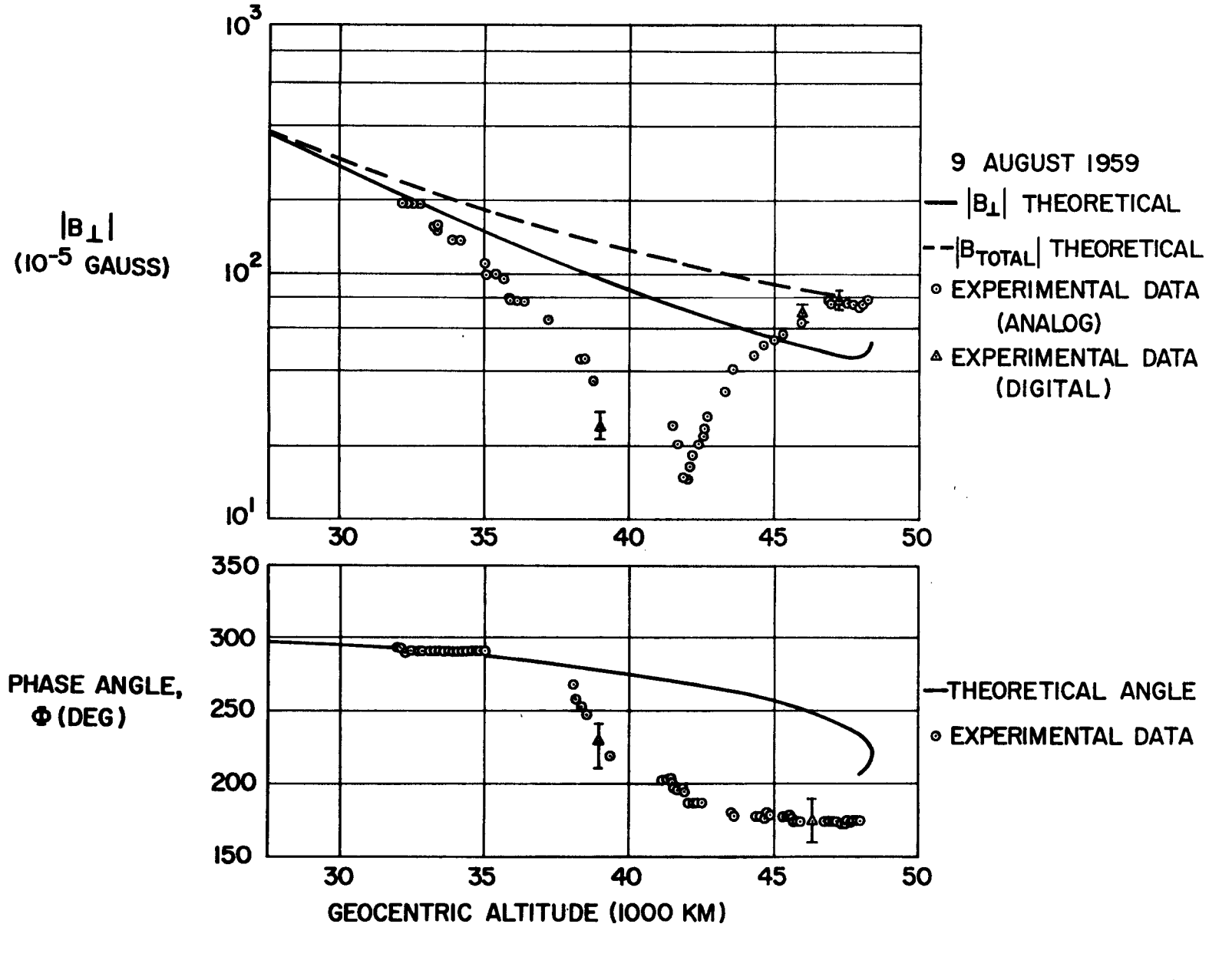

Figure 2. Field Amplitude And Phase Angle In The Deviation Region

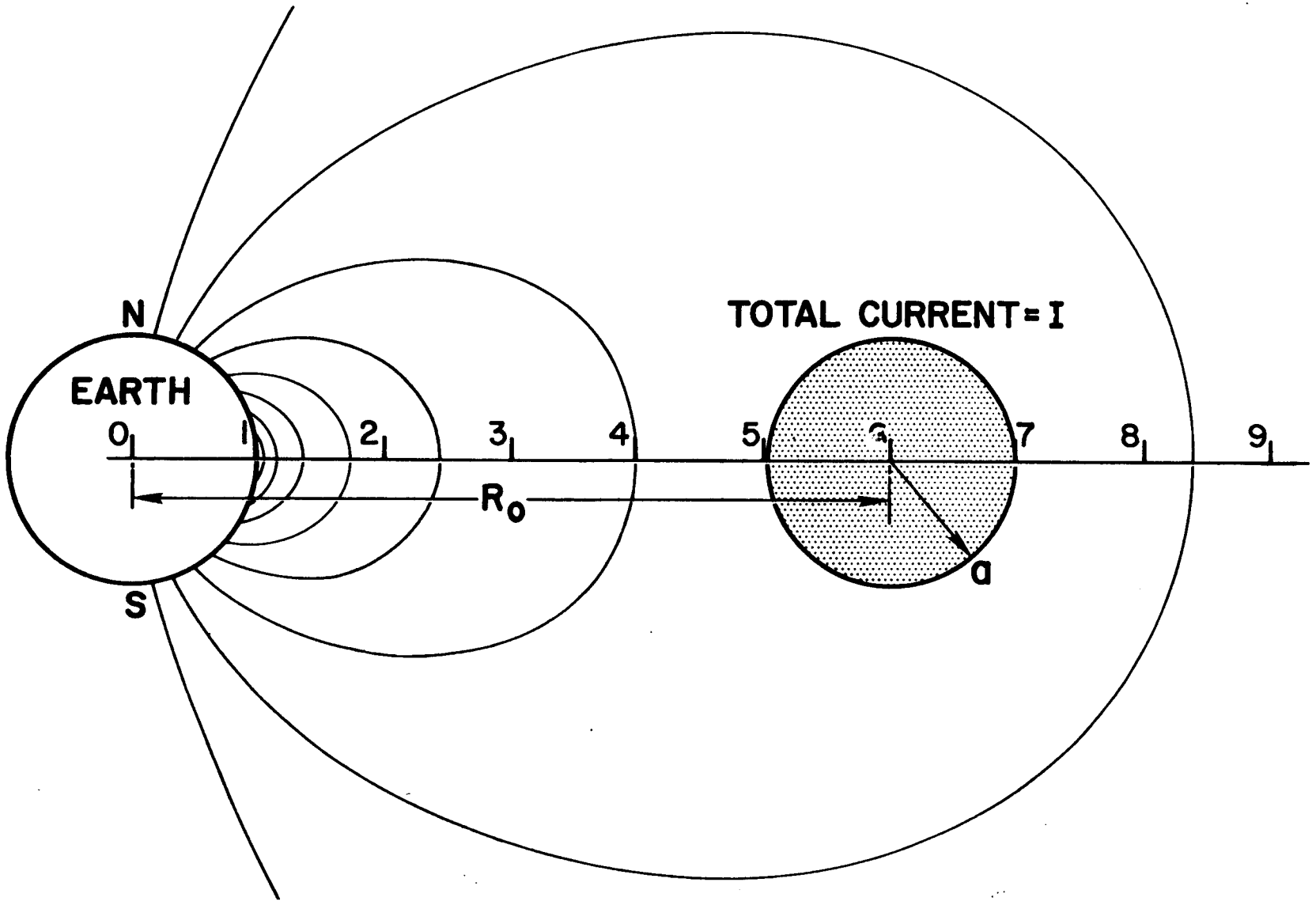

Figure 3. The Ring-Current Model

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See text for correct parameters

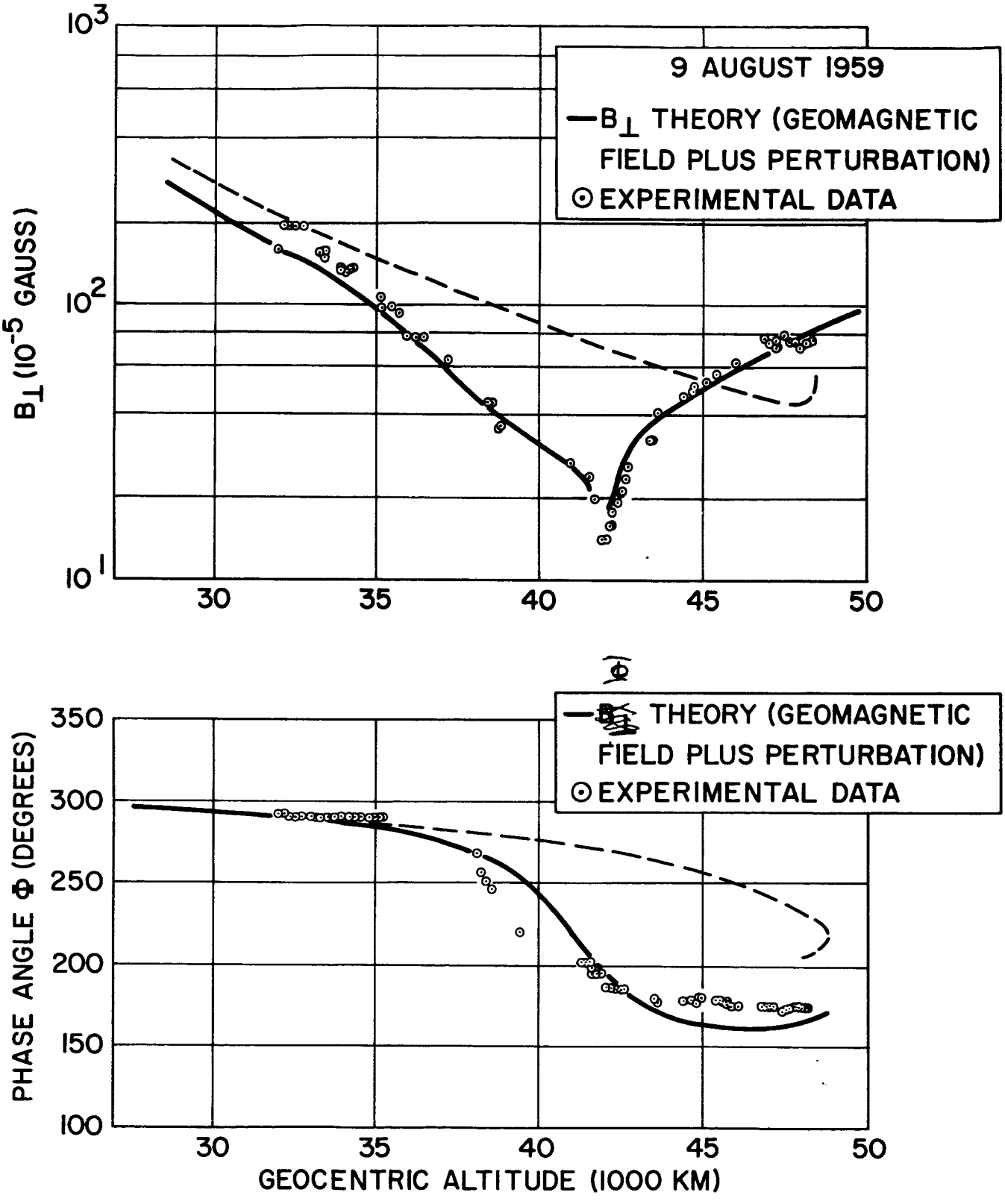

Figure 4. Comparison Between The Results Of The Model Calculation And Explorer VI Data

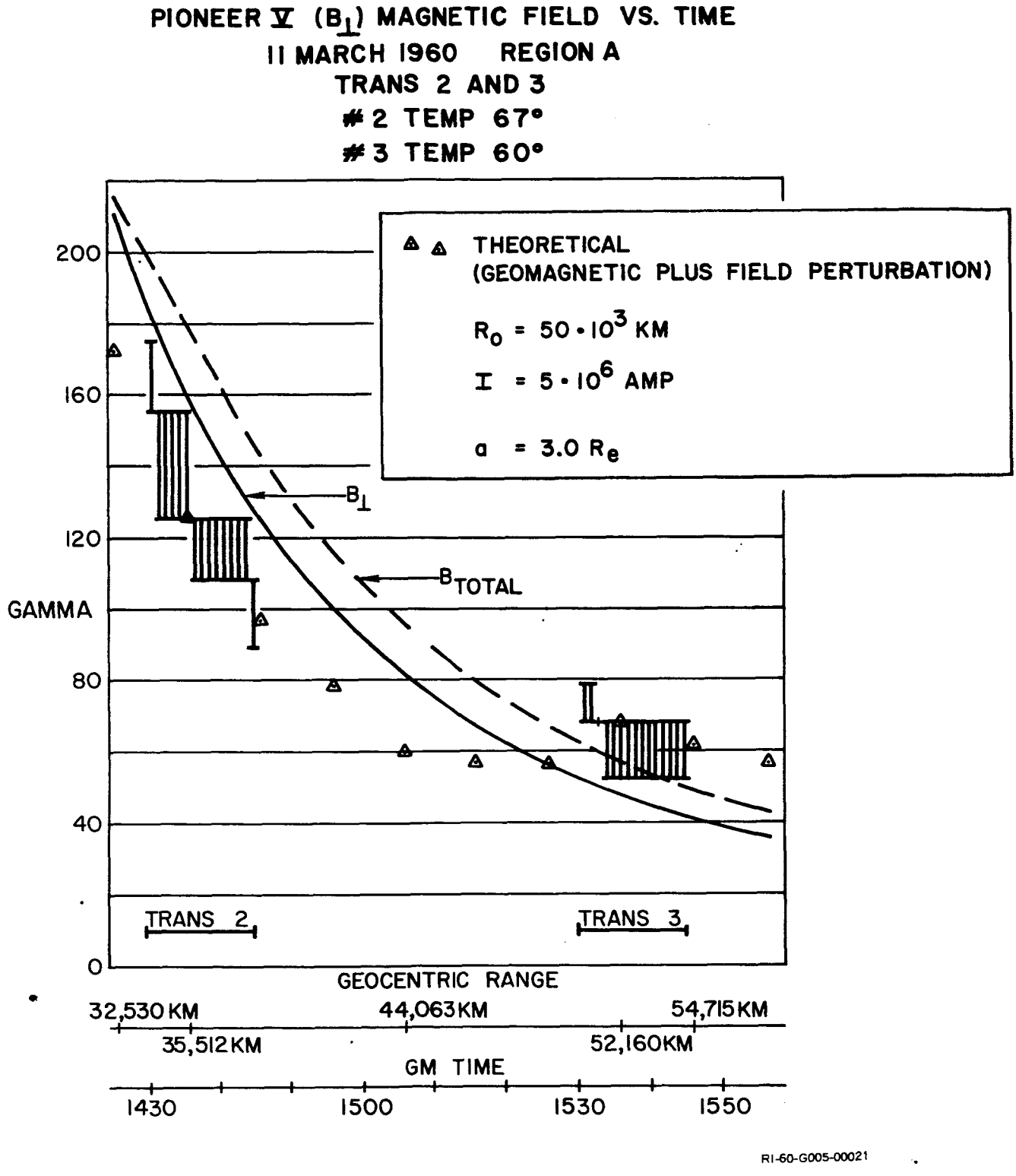

Figure 5. Comparison Between The Results Of The Model Calculation And Pioneer V Data